PHOTOVOLTAIC POWER CONTROL USING MPPT AND BOOST CONVERTER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology in Electrical Engineering

By

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Department of Electrical Engineering
National Institute of Technology, Rourkela
May 2012

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UNDER THE GUIDANCE OF
PROF. A. K. PANDA

Department of Electrical Engineering
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Electrical Engineering Department
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CERTIFICATE

This is to certify that the Thesis Report entitled **PHOTOVOLTAIC POWER CONTROL USING MPPT AND BOOST CONVERTER submitted** by Saurav Satpathy (108EE074) of **Electrical Engineering** during May 2012 at National Institute of Technology Rourkela is an authentic work by him under my supervision and guidance.

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Saurav Satpathy

Electrical Engineering

NIT ROURKELA

ABSTRACT

In this paper utilization of a boost converter for control of photovoltaic power using Maximum Power Point Tracking (MPPT) control mechanism is presented. First the photovoltaic module is analyzed using SIMULINK software. For the main aim of the project the boost converter is to be used along with a Maximum Power Point Tracking control mechanism. The MPPT is responsible for extracting the maximum possible power from the photovoltaic and feed it to the load via the boost converter which steps up the voltage to required magnitude. The main aim will be to track the maximum power point of the photovoltaic module so that the maximum possible power can be extracted from the photovoltaic. The algorithms utilized for MPPT are generalized algorithms and are easy to model or use as a code. The algorithms are written in m files of MATLAB and utilized in simulation. Both the boost converter and the solar cell are modeled using Sim Power Systems blocks.

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Chapter 1

INTRODUCTION

1.1 INTRODUCTION

One of the major concerns in the power sector is the day-to-day increasing power demand but the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming.

Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever wherever necessary.

In order to tackle the present energy crisis one has to develop an efficient manner in which power has to be extracted from the incoming solar radiation. The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. But the disadvantage of these systems is the increased power density. Trend has set in for the use of multi-input converter units that can effectively handle the voltage fluctuations. But due to high production cost and the low efficiency of these systems they can hardly compete in the competitive markets as a prime power generation source.

The constant increase in the development of the solar cells manufacturing technology would definitely make the use of these technologies possible on a wider basis than what the scenario is presently. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy [3], [8].

1.2 LITERATURE SURVEY

The topic of solar energy utilization has been looked upon by many researchers all around the globe. It has been known that solar cell operates at very low efficiency and thus a better control mechanism is required to increase the efficiency of the solar cell. In this field researchers have developed what are now called the Maximum Power Point Tracking (MPPT) algorithms.

Mummadi Veerachary has given a detailed report on the use of a SEPIC converter in the field of photovoltaic power control. In his report he utilized a two-input converter for accomplishing the maximum power extraction from the solar cell [3].

M. G. Villalva in his both reports has presented a comprehensive method to model a solar cell using Simulink or by writing a code. His results are quite similar to the nature of the solar cell output plots [1]-[2].

P. S. Revankar has even included the variation of sun’s inclination to track down the maximum possible power from the incoming solar radiations. The control mechanism alters the position of the panel such that the incoming solar radiations are always perpendicular to the panels [9].

M. Berrera has compared seven different algorithms for maximum power point tracking using two different solar irradiation functions to depict the variation of the output power in both cases using the MPPT algorithms and optimized MPPT algorithms [8].

Ramos Hernanz has successfully depicted the modeling of a solar cell and the variation of the current-voltage curve and the power-voltage curve due the solar irradiation changes and the change in ambient temperature [10].

1.3 MOTIVATION

Photovoltaic power control is one of the burning research fields these days. Researchers are round the clock to develop better solar cell materials and efficient control mechanisms. The challenge of the project and the new area of study were the motivations behind the project.

1.4 OBJECTIVE

The basic objective would be to study MPPT and successfully implement the MPPT algorithms either in code form or using the Simulink models. Modeling the converter and the solar cell in Simulink and interfacing both with the MPPT algorithm to obtain the maximum power point operation would be of prime importance.

1.5 THESIS OUTLINE

This thesis has been broadly divided into 7 chapters. The first one being the introduction, chapter 2 is on modeling of a solar cell. Chapter 3 deals with the operation of boost converter to be used in the project. Chapter 4 is on maximum power point tracking and study of the various algorithms. In chapter 5 the simulation models are presented that are used for various simulations. Chapter 6 consists of all the simulation outputs. Conclusion and future work are listed in chapter 7.

Chapter 2

SOLAR CELL MODELING

2.1 MODELLING OF SOLAR CELL

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available but only single diode model is considered here [1], [2], [4], [7], [9] and [10].

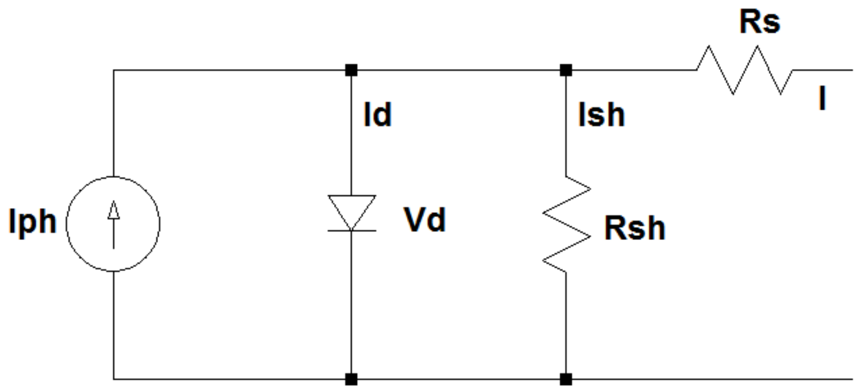

Figure 2.1: Single diode model of a solar cell

The characteristic equation for a photovoltaic cell is given by [1], [2], [4], [7], [9] and [10],

$$I = Ilg - Ios * \left[\exp\left\{q * \frac{V+I*Rs}{A*k*T}\right\} - 1\right] - \frac{V+I*Rs}{Rsh} \quad (1)$$

Where,

$$Ios = Ior * \left(\frac{T}{Tr}\right)^3 * \left[\exp\left\{q * Ego * \frac{\frac{1}{Tr}-\frac{1}{T}}{A*k}\right\}\right] \quad (2)$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * lambda \quad (3)$$

I & V : Cell output current and voltage;

Ios : Cell reverse saturation current;

T : Cell temperature in Celsius;

k : Boltzmann's constant, $1.38 * 10^{-19}$ J/K;

q : Electron charge, $1.6*10^{-23}$ C;

Ki : Short circuit current temperature coefficient at Iscr;

lambda : Solar irradiation in W/m^2;

Iscr : Short circuit current at 25 degree Celsius;

Ilg : Light-generated current;

Ego : Band gap for silicon;

A : Ideality factor;

Tr : Reference temperature;

Ior : Cell saturation current at Tr;

Rsh : Shunt resistance;

Rs : Series resistance;

The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance [7].

$$I = Np * Ilg - Np * Ios * \left[\exp\left\{q * \frac{\frac{V}{Ns}+I*\frac{Rs}{Np}}{A*k*T}\right\} - 1\right] - \frac{V*\left(\frac{Np}{Ns}\right)+I*Rs}{Rsh} \tag{4}$$

The I-V and P-V curves for a solar cell are given in the following figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

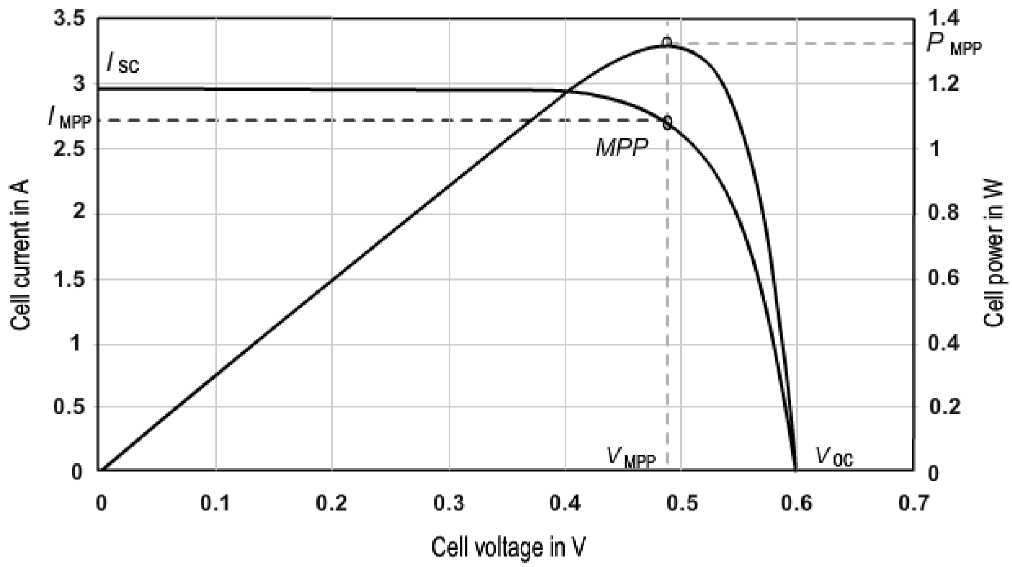

Figure 2.2: P-V I-V curve of a solar cell at given temperature and solar irradiation

2.2 EFFECT OF VARIATION OF SOLAR IRRADIATION

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated [7] and [10].

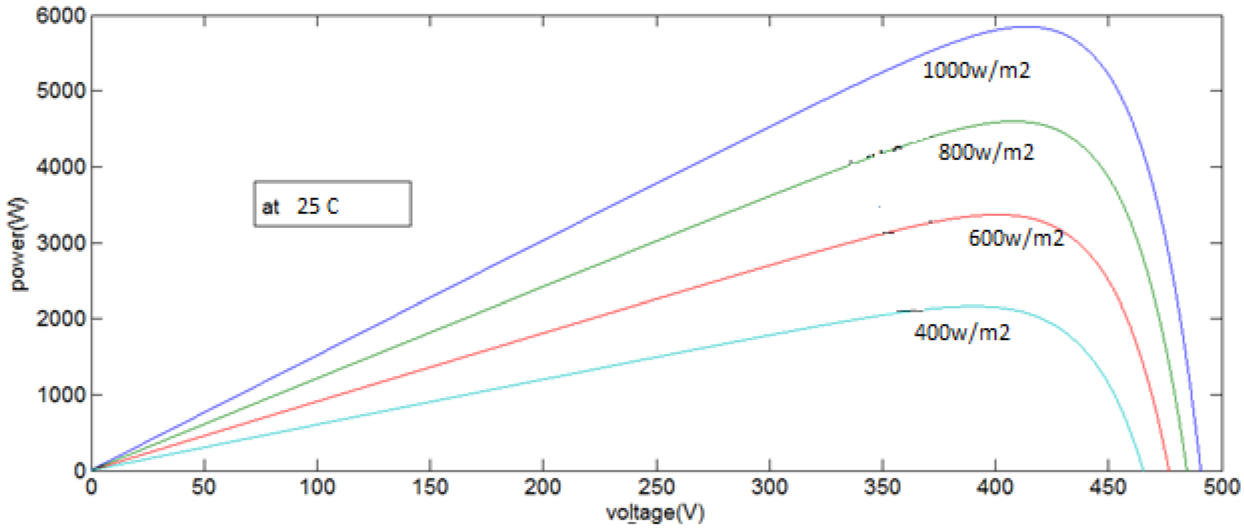

Figure 2.3: Variation of P-V curve with solar irradiation

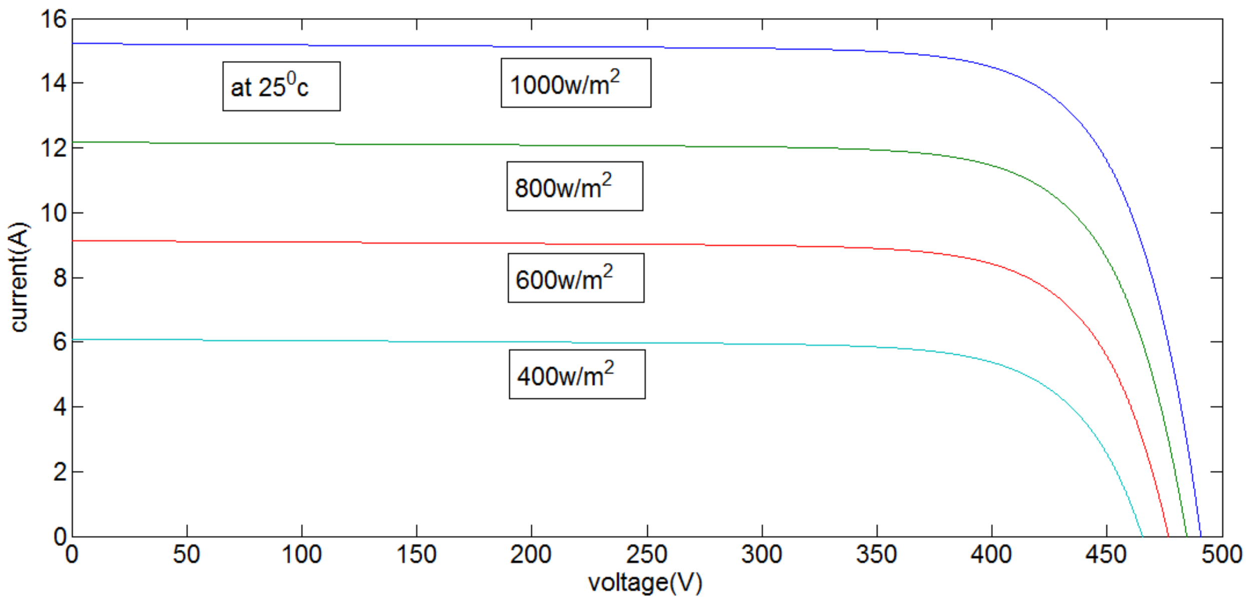

Figure 2.4: Variation of I-V curve with solar irradiation

2.3 EFFECT OF VARIATION OF TEMPERATURE

On the contrary the temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the efficiency of the solar cell is reduced [7] and [10].

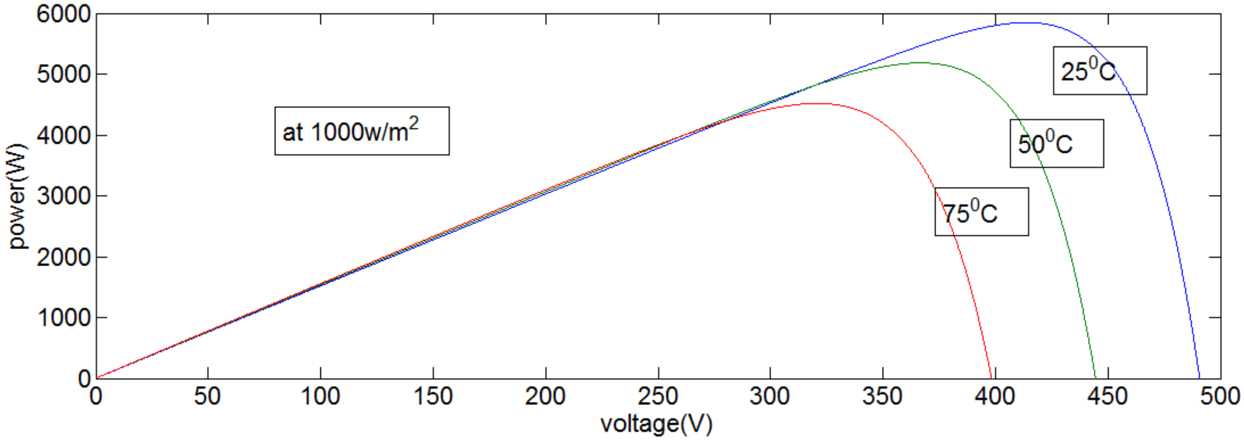

Figure 2.5: Variation of P-V curve with temperature

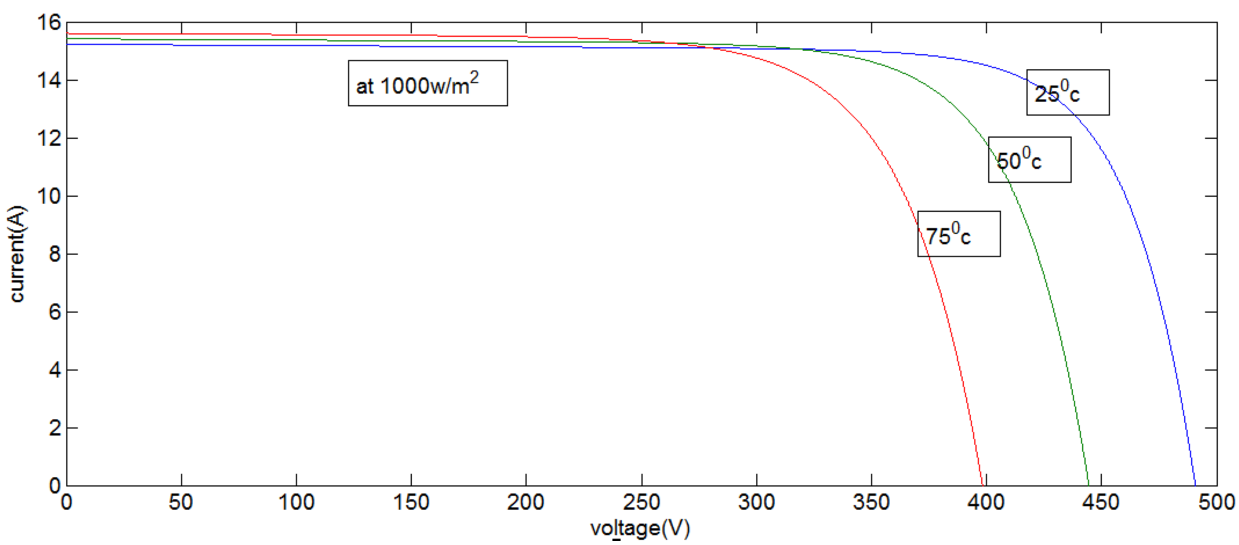

Figure 2.6: Variation of I-V with temperature

Chapter 3

BOOST CONVERTER

3.1 BOOST CONVERTER

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change [11] and [12].

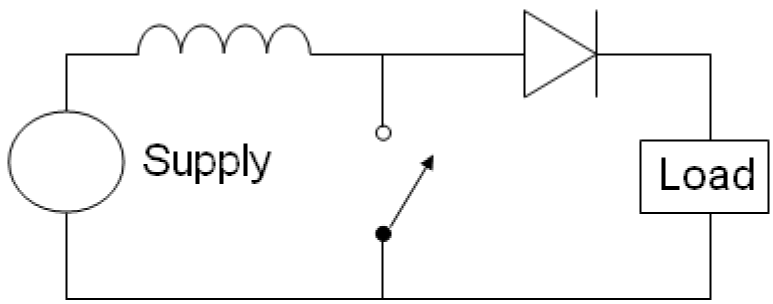

Figure 3.1: A boost converter

3.2 MODES OF OPERATION

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation [12].

3.2.1 Charging Mode

In this mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying [11]. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

3.2.2 Discharging Mode

In this mode of operation; the switch is open and the diode is forward biased [11]. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

3.3 WAVEFORMS

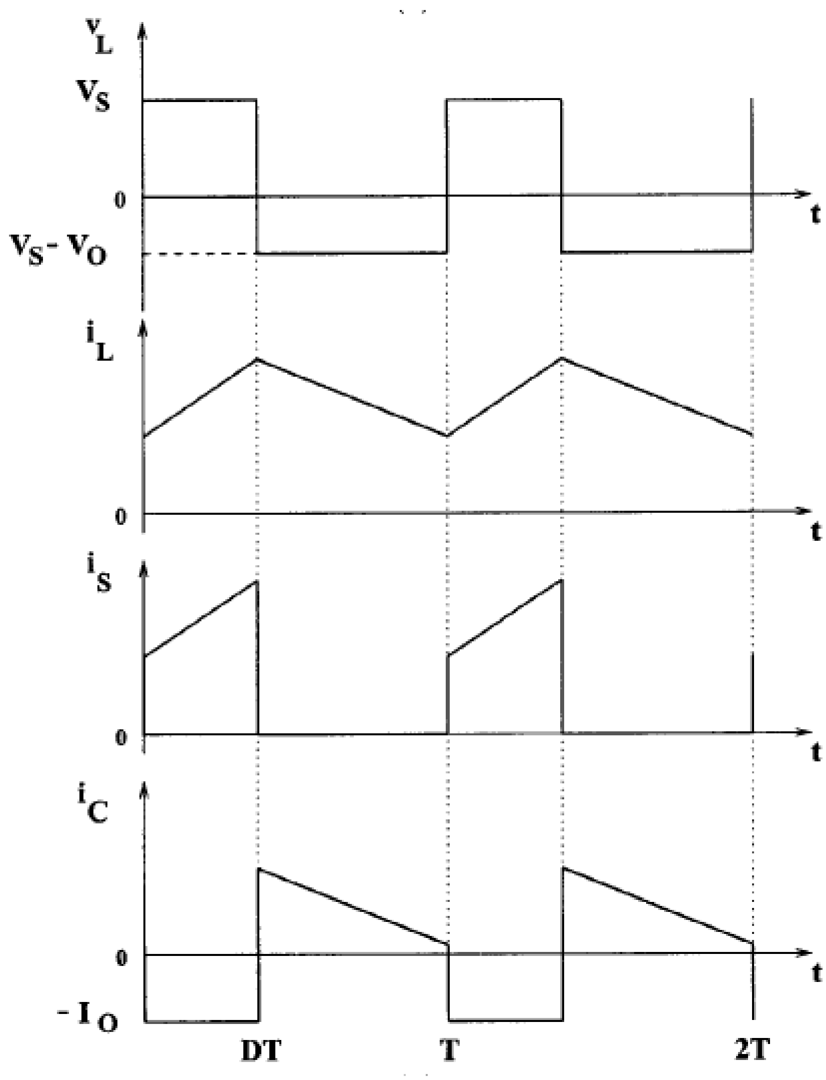

Figure 3.2: Waveforms of boost converter

Chapter 4

MAXIMUM POWER POINT TRACKING

4.1 MAXIMUM POWER POINT TRACKING

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is varied by using a mppt algorithm. Few of the many algorithms are listed below [3], [4], [5] and [8].

A boost converter is used on the load side and a solar panel is used to power this converter.

4.2 METHODS FOR MPPT

There are many methods used for maximum power point tracking a few are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

4.2.1 Perturb and Observe method

This method is the most common. In this method very less number of sensors are utilized [5] and [6]. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples$\frac{dP}{dV}$. If $\frac{dP}{dV}$ is positive, then the algorithm increases the voltage value towards the MPP until $\frac{dP}{dV}$is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP).

4.2.2 Incremental Conductance method

This method uses the PV array's incremental conductance $\frac{dI}{dV}$ to compute the sign of $\frac{dP}{dV}$. When $\frac{dI}{dV}$ is equal and opposite to the value of I/V (where $\frac{dP}{dV} = 0$) the algorithm knows that the maximum power point is reached and thus it terminates and returns the corresponding value of operating voltage for MPP. This method tracks rapidly changing irradiation conditions more accurately than P&O method. One complexity in this method is that it requires many sensors to operate and hence is economically less effective [5] and [6].

P=V*I

Differentiating w.r.t voltage yields;

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} \tag{5}$$

$$\frac{dP}{dV} = I * \left(\frac{dV}{dV}\right) + V * \left(\frac{dI}{dV}\right) \tag{6}$$

$$\frac{dP}{dV} = I + V * \left(\frac{dI}{dV}\right) \tag{7}$$

When the maximum power point is reached the slope $\frac{dP}{dV} = 0$. Thus the condition would be;

$$\frac{dP}{dV} = 0 \tag{8}$$

$$I + V * \left(\frac{dI}{dV}\right) = 0 \tag{9}$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{10}$$

4.2.3 Parasitic Capacitance method

This method is an improved version of the incremental conductance method, with the improvement being that the effect of the PV cell's parasitic union capacitance is included into the voltage calculation [5] and [6].

4.2.4 Constant Voltage method

This method which is a not so widely used method because of the losses during operation is dependent on the relation between the open circuit voltage and the maximum power point voltage. The ratio of these two voltages is generally constant for a solar cell, roughly around 0.76. Thus the open circuit voltage is obtained experimentally and the operating voltage is adjusted to 76% of this value [8].

4.2.5 Constant Current method

Similar to the constant voltage method, this method is dependent on the relation between the open circuit current and the maximum power point current. The ratio of these two currents is generally constant for a solar cell, roughly around 0.95. Thus the short circuit current is obtained experimentally and the operating current is adjusted to 95% of this value [8].

The methods have certain advantages and certain disadvantages. Choice is to be made regarding which algorithm to be utilized looking at the need of the algorithm and the operating conditions. For example, if the required algorithm is to be simple and not much effort is given on the reduction of the voltage ripple then P&O is suitable. But if the algorithm is to give a definite operating point and the voltage fluctuation near the MPP is to be reduced then the IC method is suitable, but this would make the operation complex and more costly.

4.3 FLOW CHART OF MPPT ALGORITHMS

Two of the most widely used methods for maximum power point racking are studied here. The methods are

1. Perturb & Observe Method.
2. Incremental Conductance Method.

The flow charts for the two methods are shown below.

Flow chart for perturb & observe:

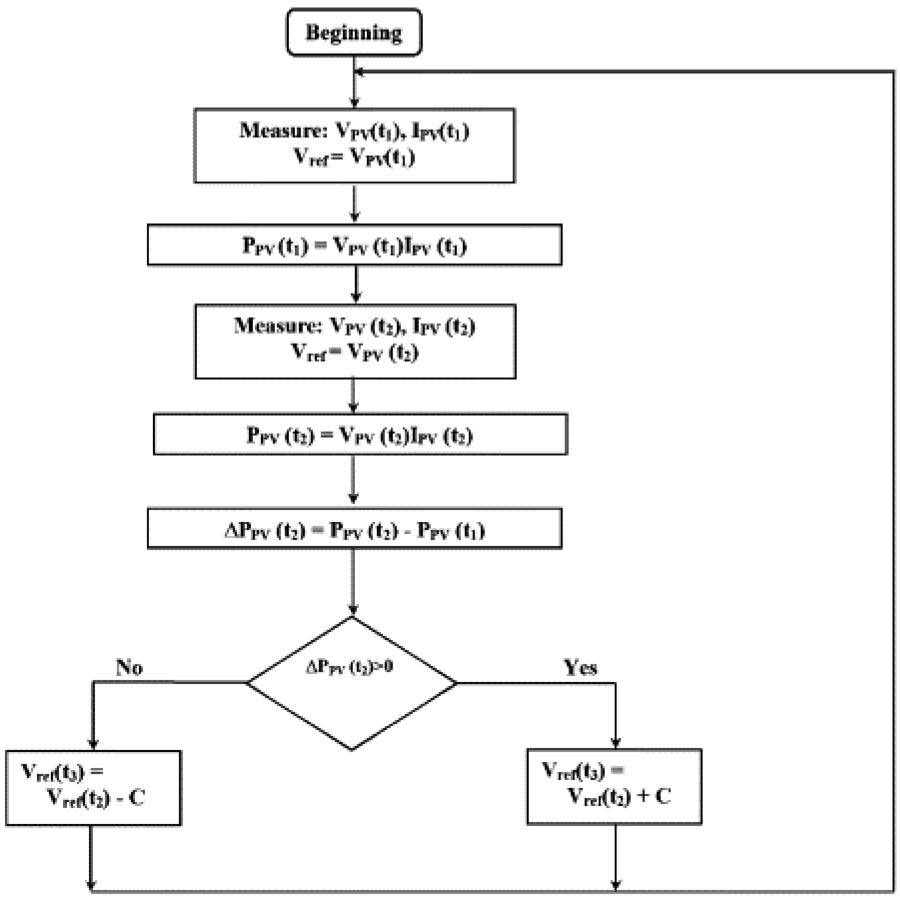

Figure 4.1: Flow chart of perturb & observe

Flow chart of incremental conductance method:

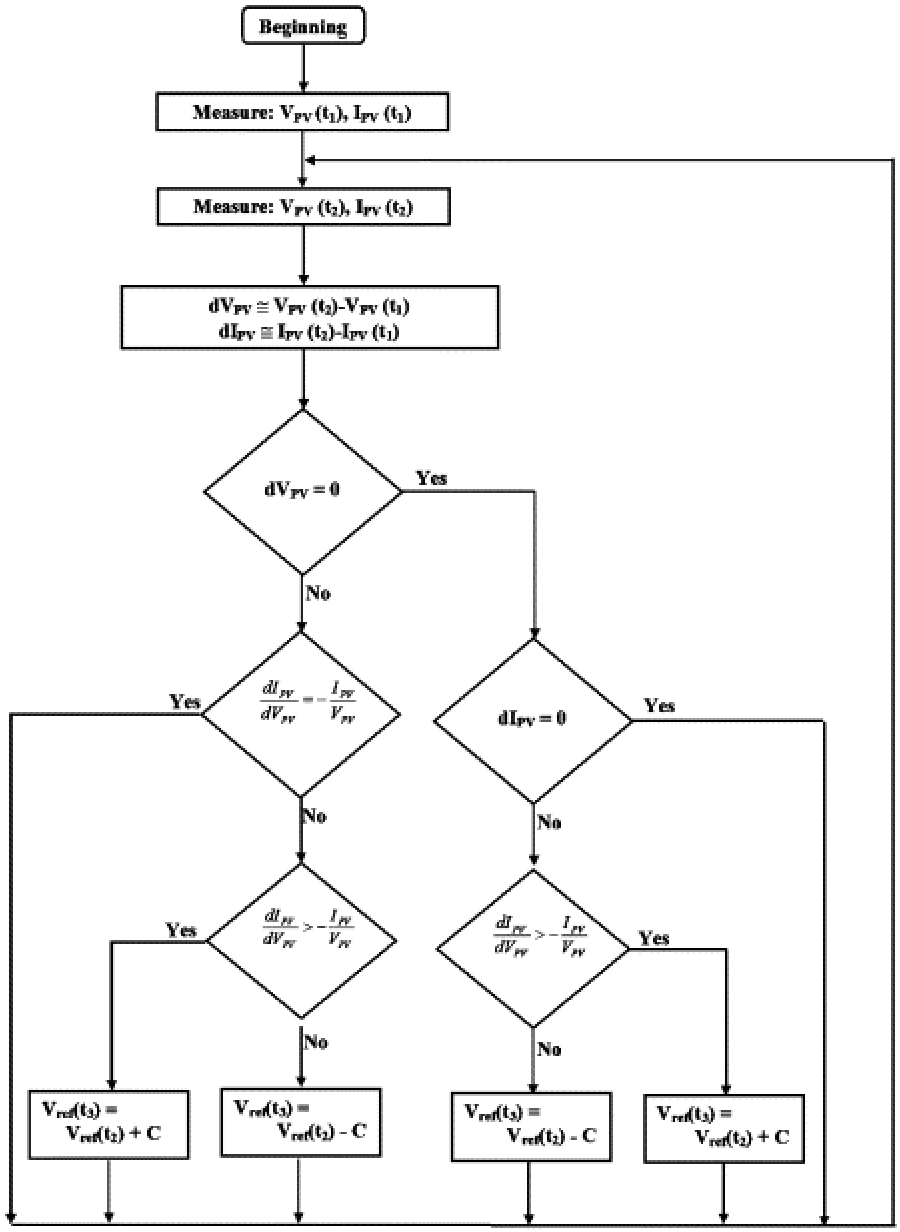

Figure 4.2: Flow chart of incremental conductance method

These two algorithms are implemented using the Embedded MATLAB function of Simulink, where the codes written inside the function block are utilized to vary certain signals with respect to the input signals.

Chapter 5

SIMULATION

5.1 SIMULINK MODEL INCREMENTAL CONDUCTANCE METHOD

The Simulink model used for the implementation of the required solar cell and boost converter system is as shown. This is for the incremental conductance method.

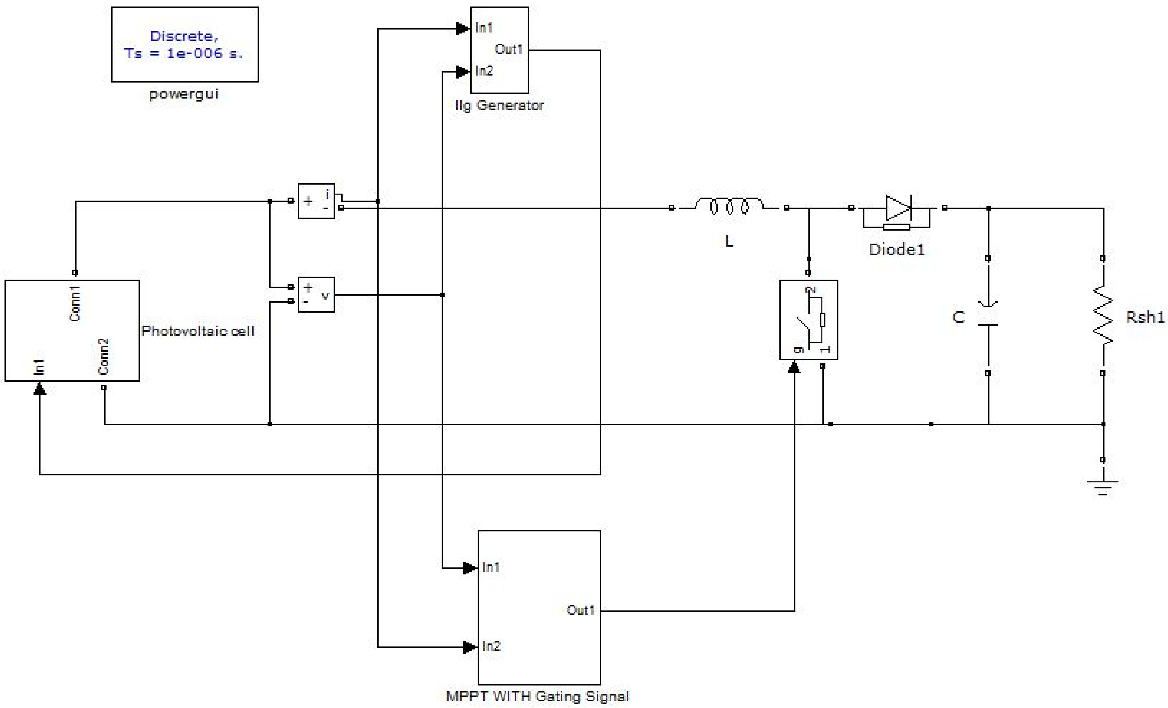

Figure 5.1: Model of solar cell with boost converter and MPPT system

Here the solar cell is represented by a block named ‘Photovoltaic cell’. The MPPT and gating signal generator are shown in a single unit called ‘MPPT with Gating Signal’. The ‘Ilg Generator’ is basically the photo-generated current that is given as input to the single diode model of the cell [1], [2] and [7].

Other elements of the model constitute the boost converter, which consists of a 0.2 mH inductor and a 1 mF capacitor. This boost converter is used to step up the voltage to the required value. The gating signal to the boost converter is generated by comparing the signal generated by the MPPT algorithm to a repeating sequence operating at a high frequency. The load is a 10 ohm resistance.

The various blocks are shown in the unmasked form later in this chapter.

5.1.1 Photovoltaic Cell

The solar cell was modeled in the single diode format. This consists of a 0.1 ohm series resistance and an 8 ohm parallel resistance. This was modeled using the Sim Power System blocks in the MATLAB library. The Simulink model is as shown.

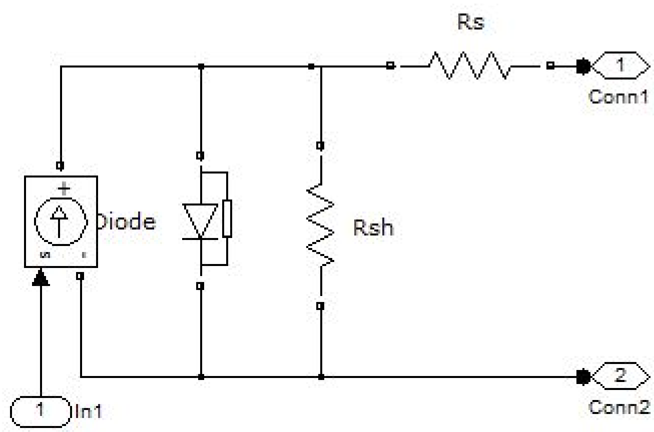

Figure 5.2: Solar cell modeled in single diode format

A controlled current source is utilized to drive the solar cell. The control signal is provided by the Ilg generator unit. The Ilg generator takes into account the number of series connected, number of parallel connected solar cells and the temperature to determine the input signal from the solar cell [1], [2], [6] and [7].

5.1.2 Ilg Generator Unit

As stated above this unit is responsible for providing the input to the solar cell [1], [2] and [7]. This block is simulated using the Simulink blocks available in the MATLAB library. This unit gives the light generated current using the characteristic equations modeled in the form of function blocks.

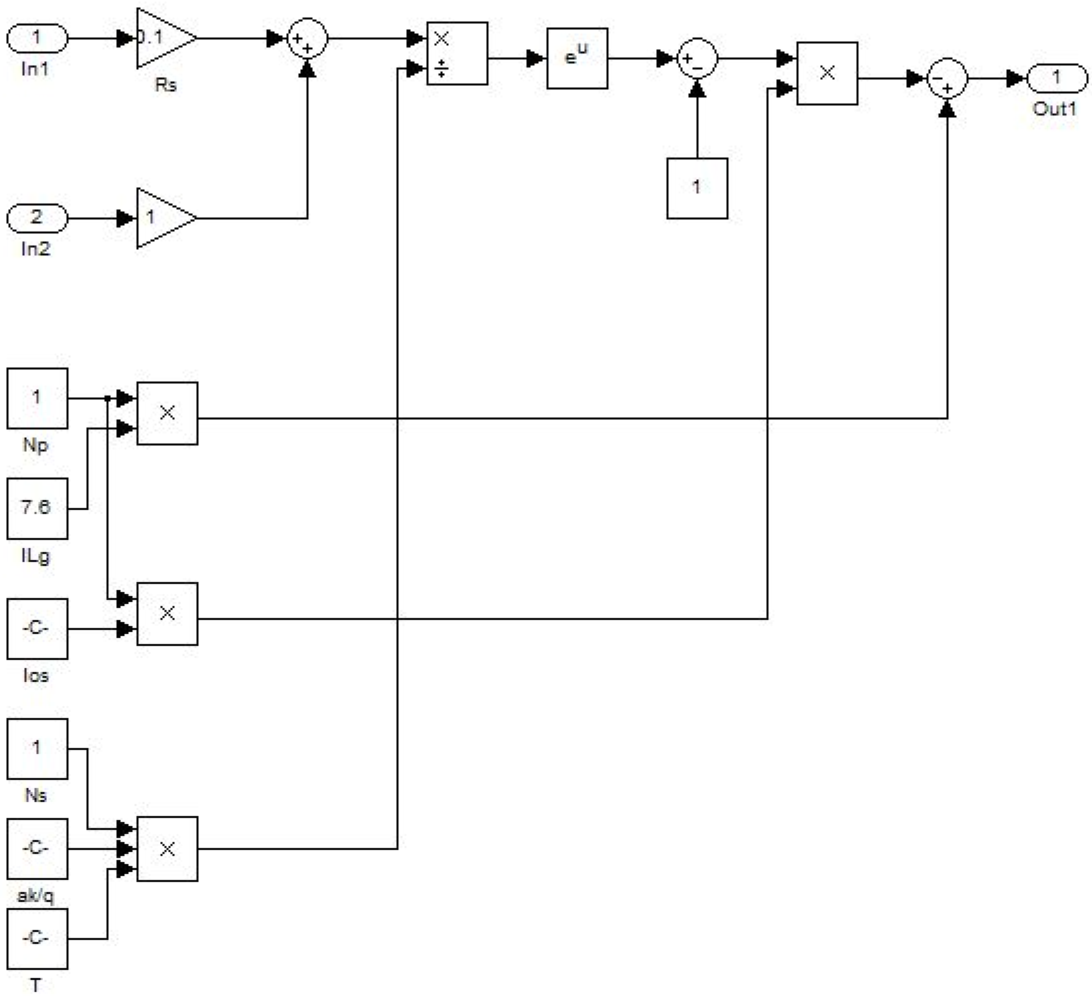

Figure 5.3: The Ilg generator unit

5.1.3 MPPT with Gating Signal Unit

This is the most important unit of the system under consideration. This can be broken down into two different units, namely

1. The MPPT unit
2. The gating signal generator unit

Both the units are composed of Simulink blocks, with the MPPT algorithm being designed using an Embedded MATLAB function [4], [5] and [9].

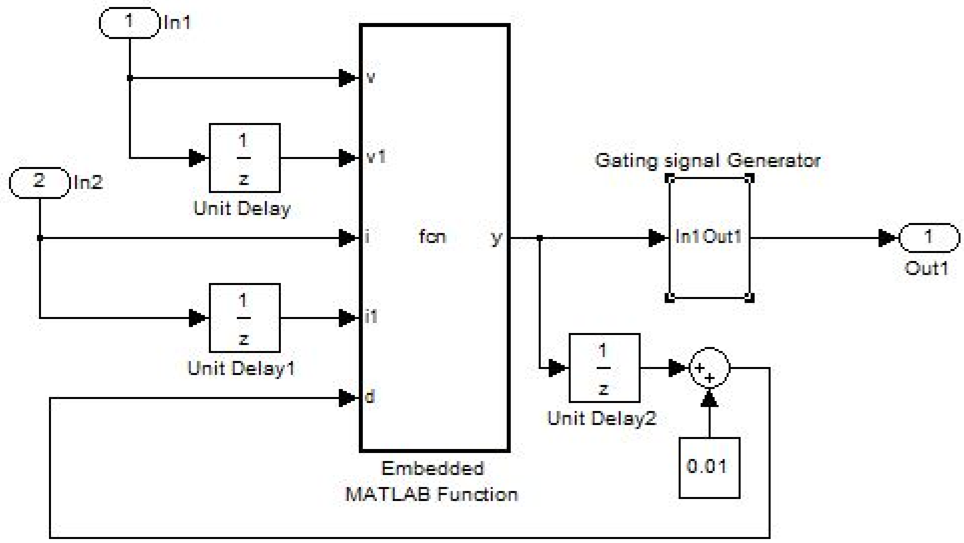

Figure 5.4: MPPT with gating signal unit

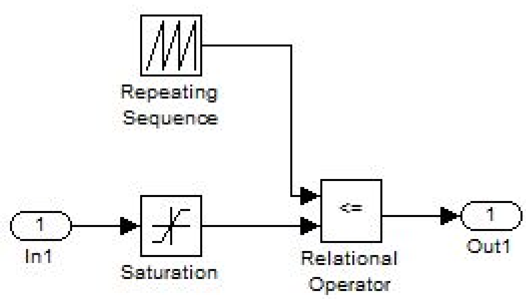

Figure 5.5: The gating signal unit

The MPPT algorithm in this unit is the incremental conductance method where the change in current, change in voltage, instantaneous voltage and instantaneous current values are taken into account to do the necessary duty cycle variations.

5.2 MODEL FOR PERTURB & OBSERVE ALGORITHM

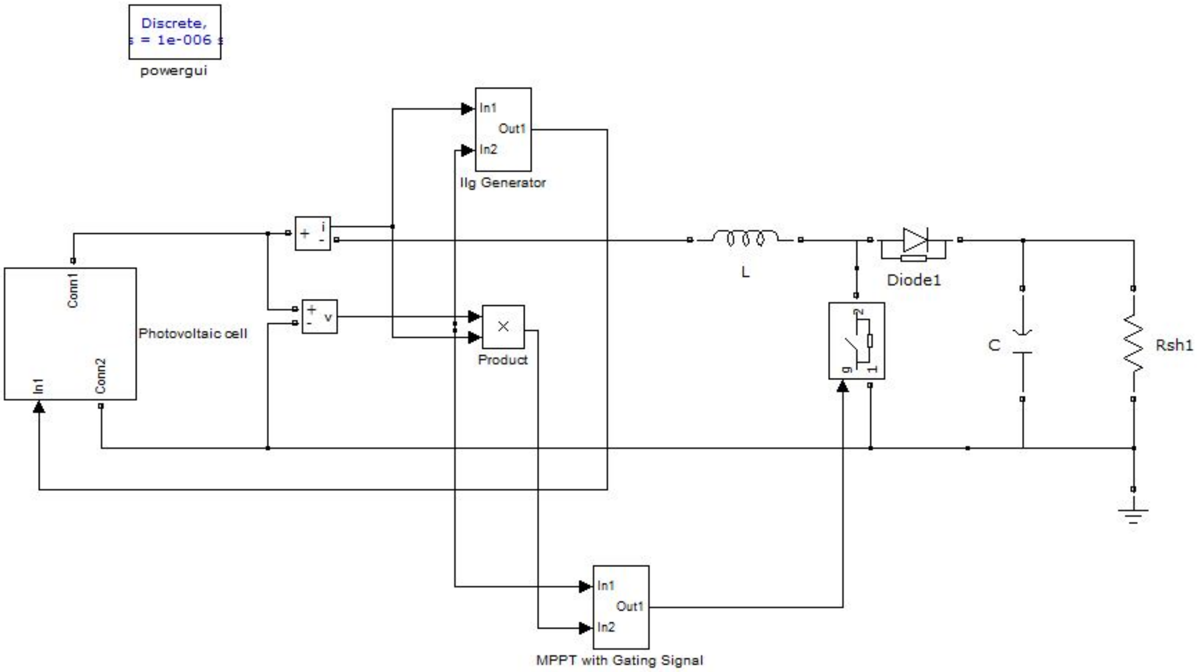

Figure 5.6: Model with P&O algorithm

The MPPT unit for this method utilizes the power and the voltage values instead of the current and voltage values as in incremental conductance method. Rest every unit is similar to the previous model units [8].

The repeating sequence being utilized in the model has an operating frequency of 10 KHz. This is also the frequency of the gating signal.

Chapter 6

SIMULATION RESULTS

6.1 SOLAR CELL SIMULATION RESULTS

The simulation of a solar cell was done using MATLAB and SIMULINK. The PV and IV curves from the simulation are as shown.

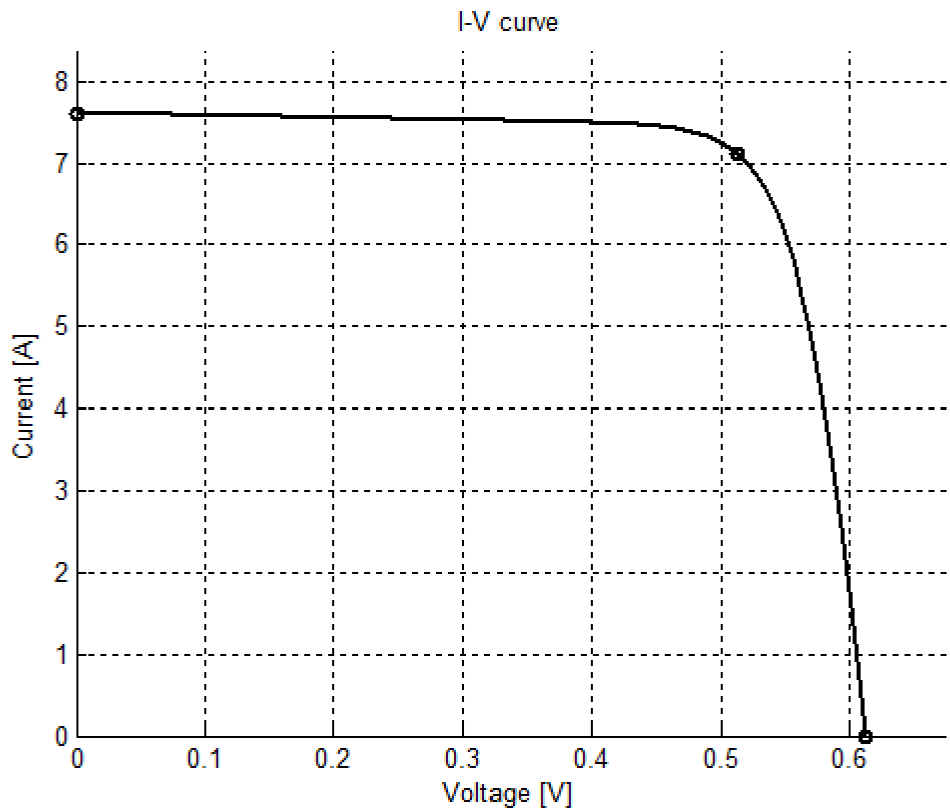

Figure 6.1: I-V characteristics of a solar cell

The parameters were obtained for a generalized solar cell. The plot is similar to the theoretically known plot of the solar cell voltage and current. The peak power is denoted by a circle in the plot. Since only one solar cell in series is considered, hence the solar output voltage is less (0.61V) in this case. The

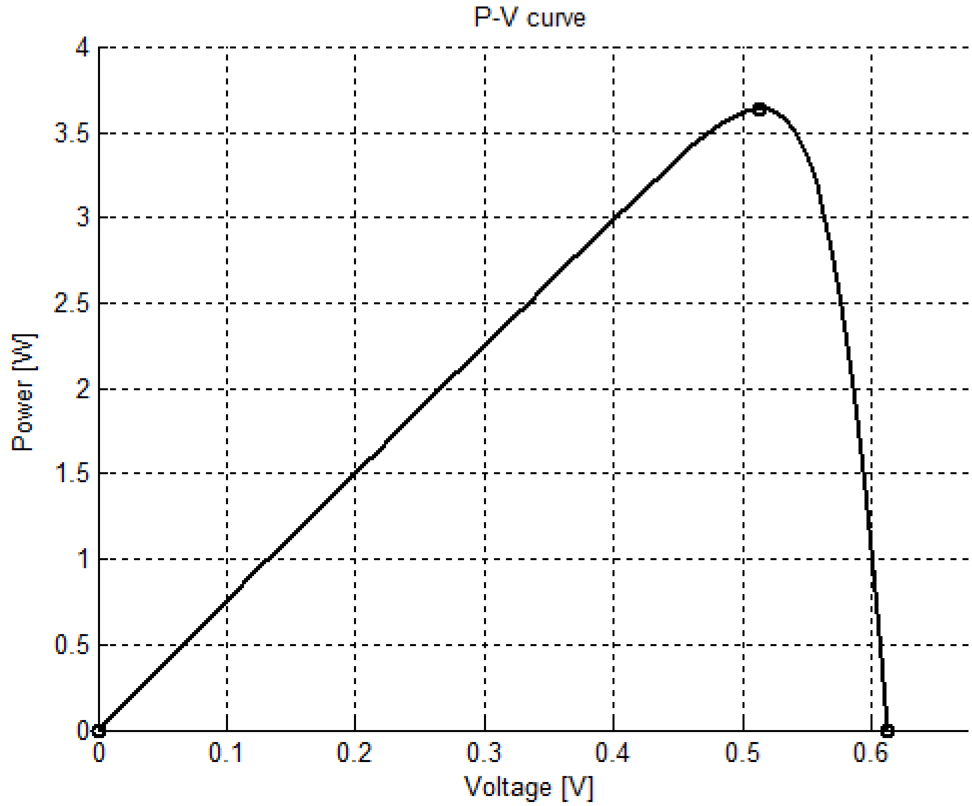

Figure 6.2: P-V characteristics of a solar cell

This plot gives the solar output power against the solar output voltage. This clearly abides by the theoretical plot that was shown previously. The maximum power point is marked with a small circle. The initial part of the plot from 0 V to the maximum power point voltage is a steady slope curve but after the maximum power point the curve is a steeply falling curve.

6.2 SIMULATION RESULTS OF THE CONVERTER MODEL

The simulations were carried out in Simulink and the various voltages, currents and power plots were obtained.

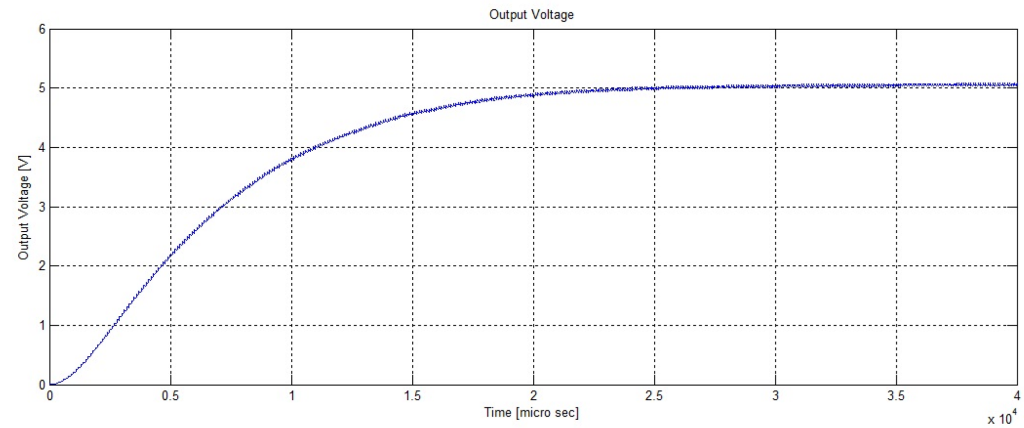

Figure 6.3: Output Voltage

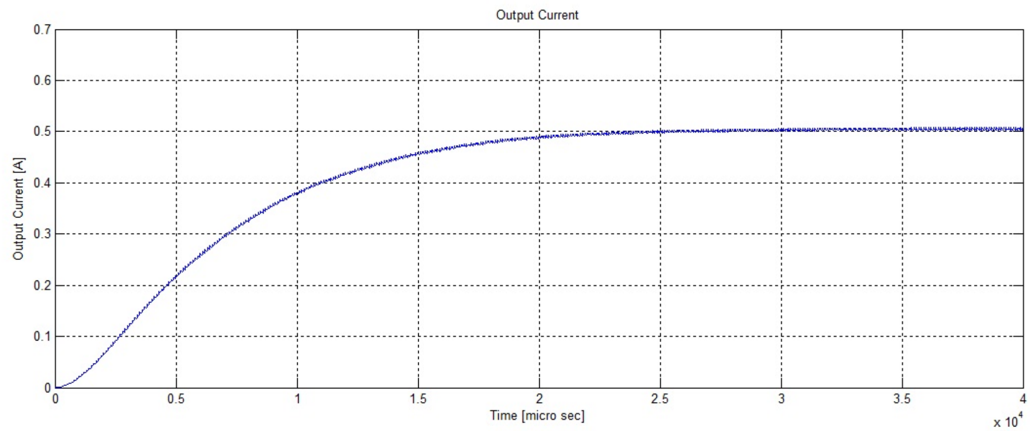

Figure 6.4: Output Current

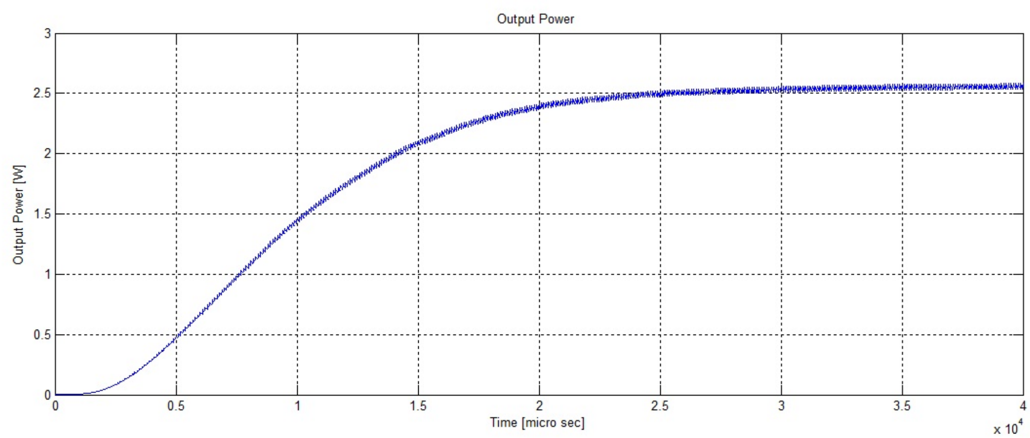

Figure 6.5: Output Power

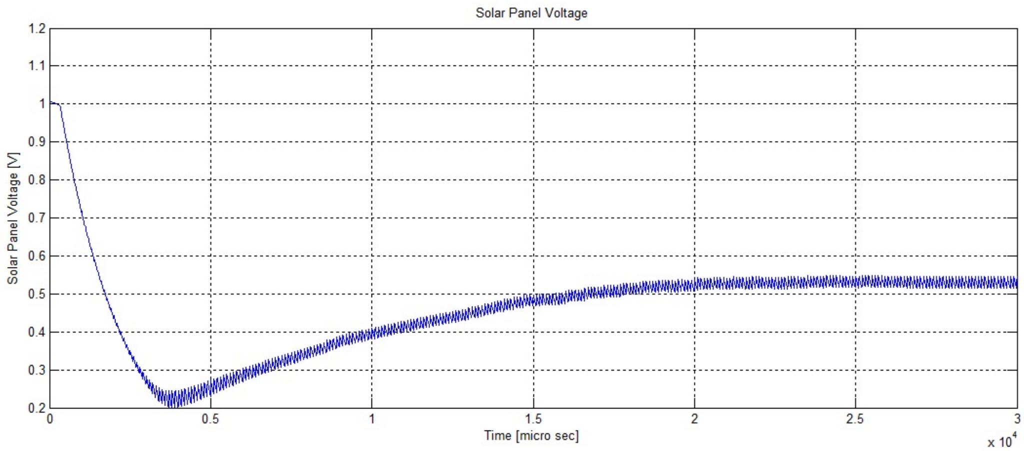

Figure 6.6: Solar Output Voltage

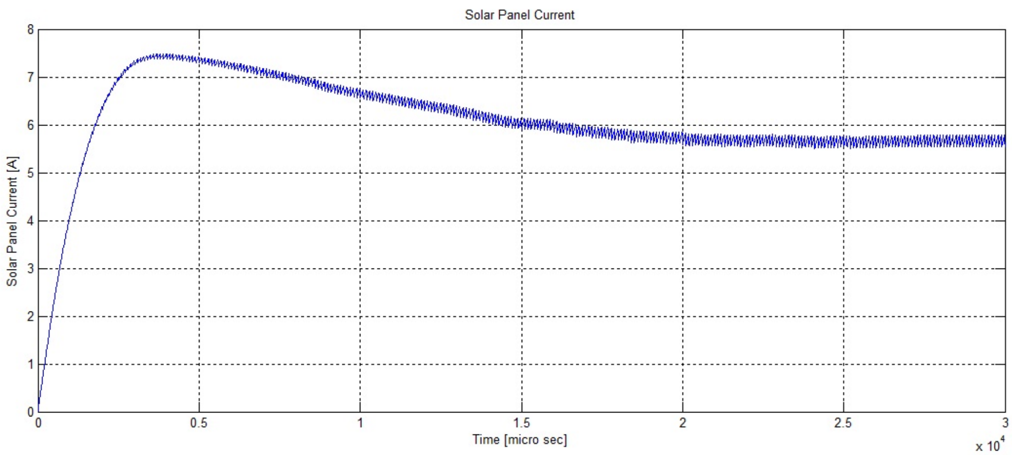

Figure 6.7: Solar Output Current

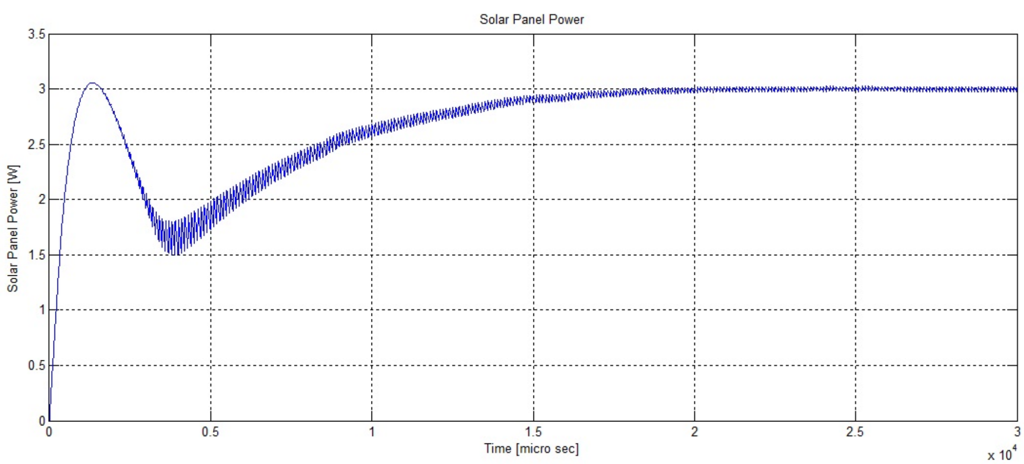

Figure 6.8: Solar Output Power

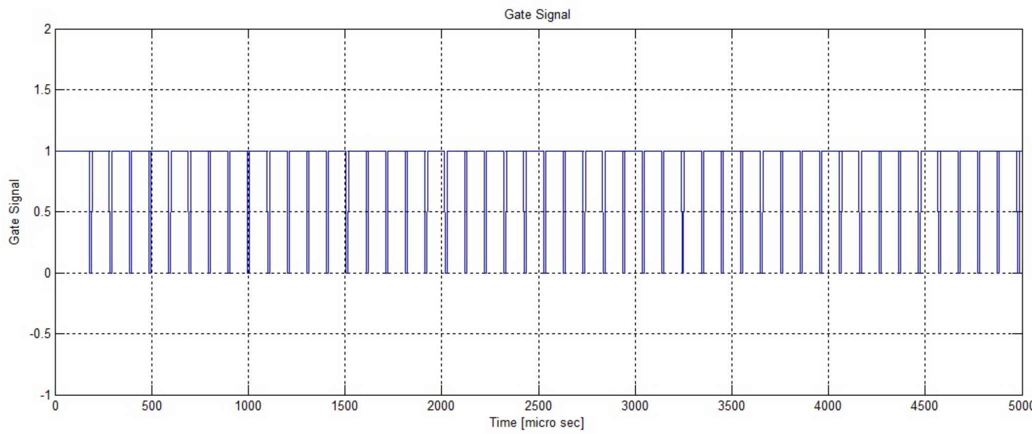

Figure 6.9: Gating Signal

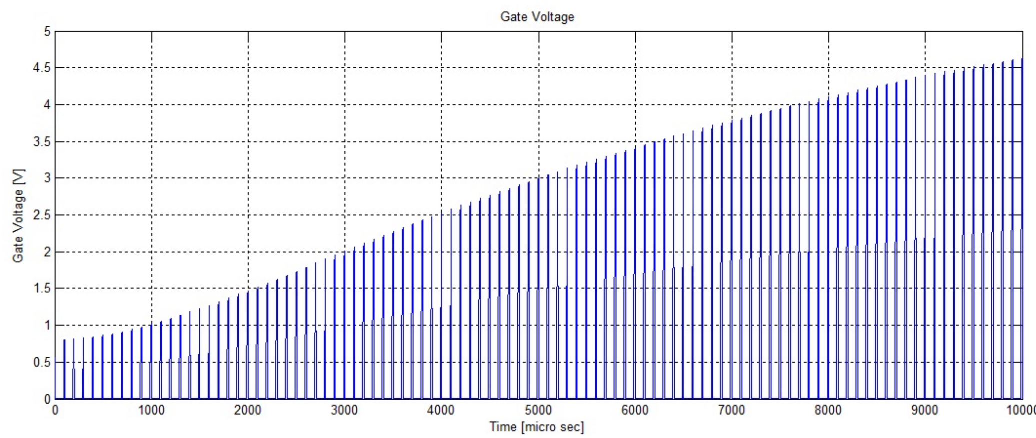

Figure 6.10: Voltage across Switch

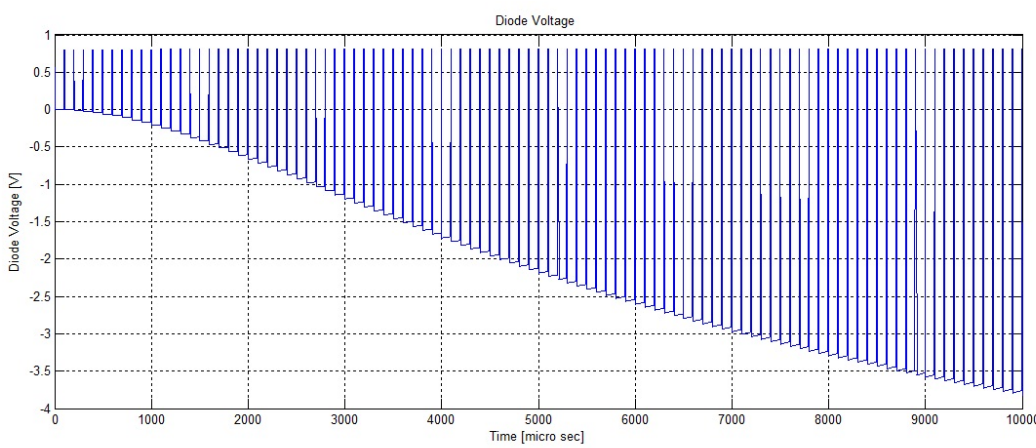

Figure 6.11: Diode Voltage

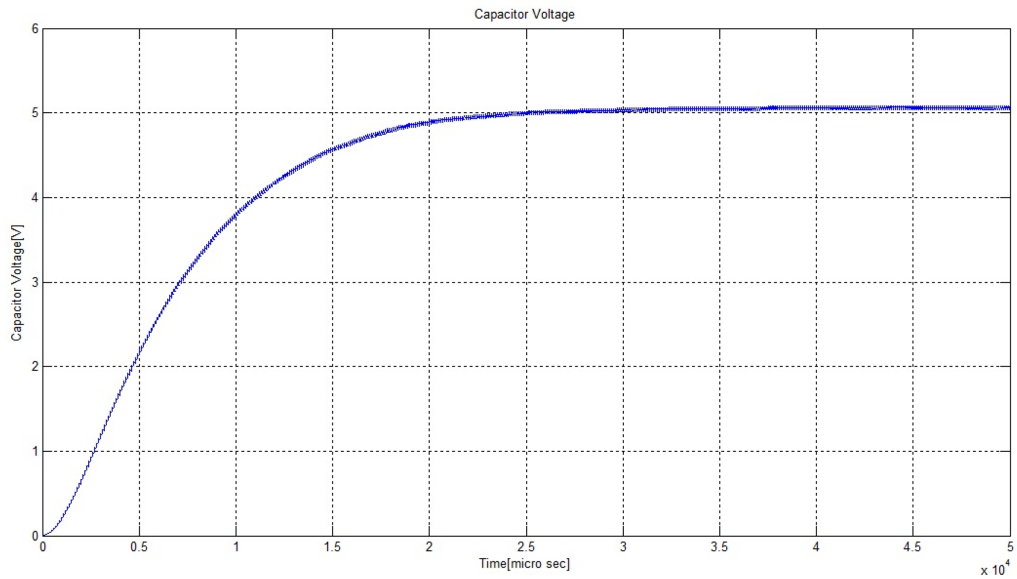

Figure 6.12: Capacitor Voltage

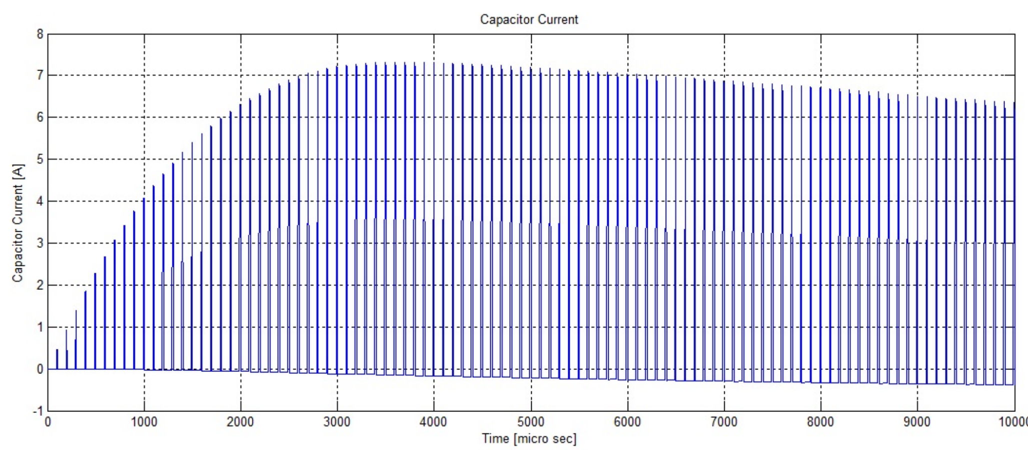

Figure 6.13: Capacitor Current

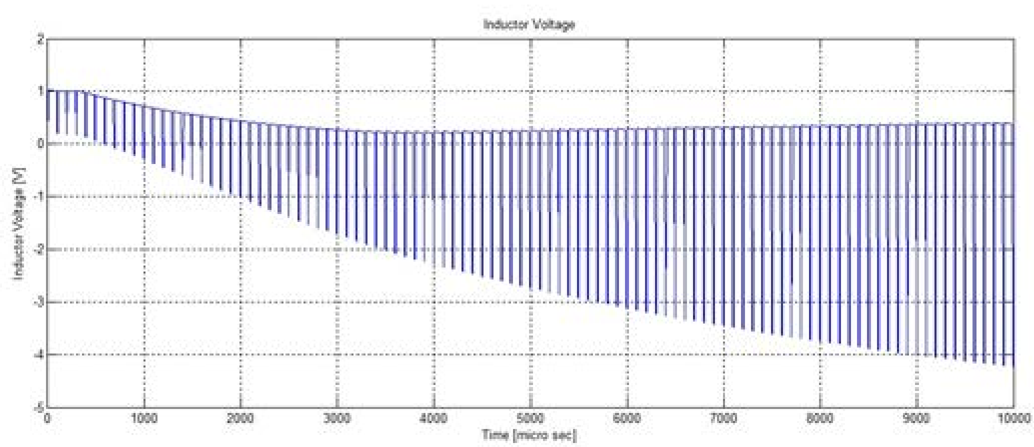

Figure 6.14: Inductor Voltage

Chapter 7

CONCLUSION & FUTURE WORK

7.1 CONCLUSION

A resistive load of 10 ohms was used with the boost converter thereby making the output current and voltage similar. The frequency of operation was 10 KHz which was set by using a repeating sequence generator. This generator was utilized for generating the pulse signal that was compared with the signal generated from the MPPT unit to give out the gating signal to the switch.

When MPPT is used there is no need to input the duty cycle, the algorithm iterates and decides the duty cycle by itself. But if MPPT had not been used, then the user would have had to input the duty cycle to the system. When there is change in the solar irradiation the maximum power point changes and thus the required duty cycle for the operation of the model also changes. But if constant duty cycle is used then maximum power point cannot be tracked and thus the system is less efficient.

The various waveforms were obtained by using the plot mechanism in MATLAB. There is a small loss of power from the solar panel side to the boost converter output side. This can attributed to the switching losses and the losses in the inductor and capacitor of the boost converter. This can be seen from the plots of the respective power curves.

7.2 FUTURE WORK

Improvement to this project can be made by tracking the maximum power point in changing environmental conditions. Environmental change can be change in solar irradiation or change in ambient temperature or even both. This can be done by using Simulink models to carry out MPPT instead of writing it code in Embedded MATLAB functions. In the Simulink models the solar irradiation and the temperature can be given as variable inputs instead of constant values as done here.

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